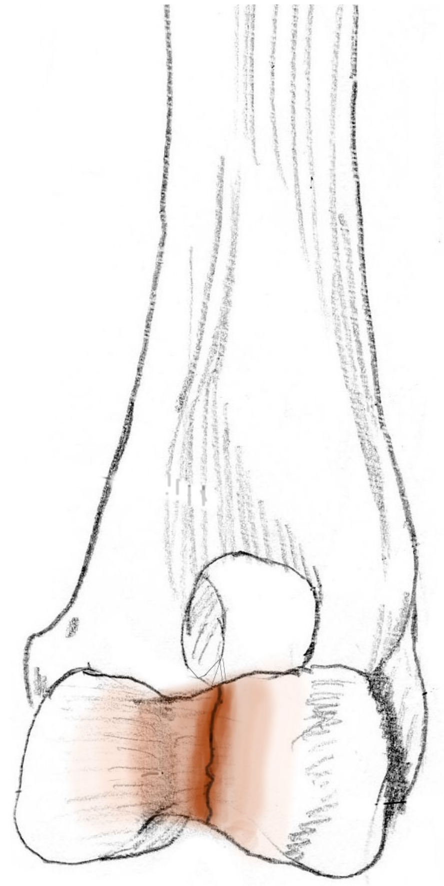

Humeral Intracondylar Fissure

Literature Review

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Tiivistelmä - Referat – Abstract

Olkaluun nivelnastan halkeama (HIF) on koirien kyynärnivelen sairaus, jota nähdään pääasiassa spanieliroduilla. Sairaus on suhteellisen harvinainen, mutta eläinlääkäreiden tietoisuuden kasvun takia sitä diagnosoidaan yhä useammin. Kirjallisuuskatsauksen tavoite on oppia enemmän sairaudesta analysoimalla sairautta kuvailevaa kirjallisuutta. Tutustuessaan tutkielmaan lukija oppii, milloin epäillä HIF:a ja mitkä ovat parhaat hoitovaihtoehdot.

HIF:n patogeneesista on olemassa kaksi teoriaa. Toisen teorian mukaan HIF on kehitykseen liittyvä olkaluun nivelnastan luutumiskeskuksien häiriö, jolloin luutumista ei tapahdu ja nivelnastan sisään jää röntgenharva linja. Vaihtoehtoisesti HIF voi olla seuraus niveleen kohdistuvien normaalien voimien vaikutuksesta skleroottiseen luuhun. Molemmat teoriat voivat olla vaikuttamassa yhtä aikaa.

HIF:n tyypillinen potilas on nuori tai keski-ikäinen spanielirotuinen koira, joka alkoi ontumaan etujalkaa ilman traumaattista taustaa tai normaalin aktiviteetin jälkeen. Joskus koira tuodaan vastaanotolle matalaenergisen kyynärnivelen murtuman takia. Taustalla voi olla hyppääminen matalilta pinnoilta. Ontumatutkimuksessa koira reagoi kyynärpään palpatioon ja manipulaatioon.

Luotettavin kuvantamismenetelmä HIF:n diagnostiikassa on tietokonetomografia ja magneettikuvaus. Röntgendiagnostiikka voi olla liian haastavaa, koska halkeama voi jäädä piiloon päälle kuvantuvan kyynärlisäkkeen varjoon. HIF:n kuvaamisessa suositellaan aina kuvata molemmat kyynärpäät, koska se on usein molemminpuolinen sairaus.

HIF:n kirurgisen hoidon tavoite on stabilisoida nivelnasta vetoruuvin avulla. Valitettavasi leikkauksen jälkeinen komplikaatioriski on korkea. Tämän vuoksi oireettoman koiran leikkausta ei ensisijaisesti suositella. Tyypilliset komplikaatiot ovat leikkausalueinfektio ja ruuvin murtuminen. Komplikaatiot johtuvat siitä, että halkeama ei luudu ja nivelnastan osien väliin jää mikroliikettä. Komplikaatioriskin minimoimiseksi on suositeltu luusiirteen käyttöä ruuvin asettamisen yhteydessä. Tavallisemmin käytetyn mediaalisen avauksen kautta asennettu ruuvi stabilisoi nivelnastaa paremmin kuin lateraalisesta avauksesta asetettu ruuvi. Mediaalisessa avauksessa ruuvin nivelsisäisen asentamisen riski on suurempi, minkä takia usein käytetään poranohjainta ja fluoroskopiaa.

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Humeral intracondylar fissure (HIF) is a disease of canine elbow joint that is mostly seen in spaniel breed. It is quite uncommon but due to growing awareness among veterinarians it has been diagnosed more often. The aim of the thesis is to learn more about the disease by reviewing the latest literature on HIF. In particular, the reader will learn when to suspect HIF and what are the best treatment options.

There are two different theories on etiology of HIF. According to one, HIF is a developmental failure of two ossification centers to fuse. Therefore, a radiolucent fissure between the ossification centers is observed in radiographs. The other theory states that it is the result of normal forces inside of an elbow acting on abnormal bone. The two theories might coexist.

The typical patient with HIF is a young or middle-aged dog of spaniel breed that started limping on a front limb without preceding traumatic accident or after normal activity. It is not rare that a dog comes with an elbow fracture after low energy trauma like jumping from low surfaces. On examination the dog would be reacting on elbow manipulation and palpation.

The best visual diagnostic tool for this type of condition is computed tomography and magnetic resonance imaging. Radiography can be challenging because the fissure is not often seen due to the overlapping olecranon. It is advised to image both elbows because the condition is often bilateral.

The treatment aims at stabilization of the condyle with a transcondylar lagged screw. Unfortunately, the complication rate is high. So, if there are no clinical signs, it is generally not recommended to treat incidental HIF surgically. The typical complications are surgical site infection and implant failure. Complications result from the inability of humeral condyle parts to heal. To overcome the high complication rate, it is suggested to use bone autograft with the screw placement. Also, the mediolateral approach of the screw placement nowadays is preferred to lateromedial. It is believed that this technique brings more stabilization to the joint. This approach brings a risk of intra-articular screw placement though. Aiming devices and fluoroscopic guidance have been used to facilitate the screw placement in this approach.

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ABBREVIATIONS

CT	Computer Tomography
FCP	Fragmented Coronoid Process
F^2T^2	Fitz Fenestrated Tubular Transcondylar screw
hdac4	Histone Deacetylase 4
HIF	Humeral Intracondylar Fissure
IOHC	Incomplete Ossification of the Humeral Condyle
MRI	Magnetic Resonance Imaging
TCS	Transcondylar Cortical Screw
UAP	Ununited Anconeal Process

INTRODUCTION

Humeral intracondylar fissure (HIF) – a disease of canine elbow joint - was first described by Marcellin-Little and his colleagues in 1994 (Marcellin-Little et al. 1994). After that the awareness of the disease has been growing among the veterinarians.

The pathogenesis of HIF is unclear. The fissure may result from the failure of two ossification centers to fuse or from the inability of sclerotic bone to withstand normal forces. The third option is that two different etiologies coexist. Piola et al. (2010) showed by magnetic resonance images that the fissure can appear de novo in the elbow, what contradicts with the theory about ossification failure. Also, the authors argued that before the appearance of the fissure, the condylar area of the studied elbow looked abnormal on MRI (Piola et al. 2010). This condition can be easily overseen on the X-ray because the X-ray beam should be perpendicular to the fissure.

The surgical treatment of HIF result in surprisingly high post-operative complication rate. Hattersley et al. (2011) studied the result of 57 dogs and reported 60% postoperative complication rate. The area of the fissure does not usually heal what leads to surgical site infection, limping and/or implant failure. The surgical technique that has been used to treat this was transcondylar screw placement. Authors argued that lagged screw is better for the stabilization of the humeral condyle (Hattersley et al. 2011). Later, in 2010 surgeons started to use medial approach to reach better stabilization (Chase et al. 2019). Because of elevated risk of intra-articulate screw placement with this approach different aiming devices and helping tools have been used (Grand 2017, Easter et al. 2020). Also, special screws and bone autographs have been used to facilitate the healing of the fissure (Charles et al. 2009, Fitzpatrick et al. 2009). Unfortunately, the latest research showed that there is a need for better surgical solutions because longer term follow-ups of the treatments made with medial approach still report unsatisfactory results (McCarthy et al. 2019, Chase et al. 2019).

This licentiate thesis reviews the latest research concerning HIF. It covers the anatomy of the elbow joint, pathogenesis of HIF, typical signs, diagnosis, treatment options and post-operative complications. Other orthopedic diseases of the elbow joint as well as repairment of complicated fractures of the elbow are beyond the scope of this thesis. The thesis also describes different treatment strategies, so the veterinary surgeon can decide which one to use for successful treatment of this condition.

REVIEW OF THE LITERATURE

1. ANATOMY OF THE ELBOW AND ITS DEVELOPMENT

The articulate surfaces of the elbow joint of the dog are formed by the distal humerus and the proximal radius and ulna. The distal humerus ends with a rounded structure called the condyle (Fig. 1), which is a multistructural element exclusive of the epicondyles (Evans and de Lahunda 2012). The condyle is divided into medial and lateral parts or the trochlea and the capitulum, respectively. The trochlea articulates with the ulna's trochlear notch and to some extent with the radial head. The capitulum articulates almost exclusively with the radial articular fovea. Just above the condyle lies the supratrochlear foramen which connects the radial and olecranon fossae (König and Liebich 2012). In a dog the foramen is closed with dense connective tissue so both fossae do not communicate. If the humerus is small enough, the foramen may be absent (Evans and de Lahunda 2012). The fossae accommodate a part of the radial head and the olecranon during elbow flexion and extension.

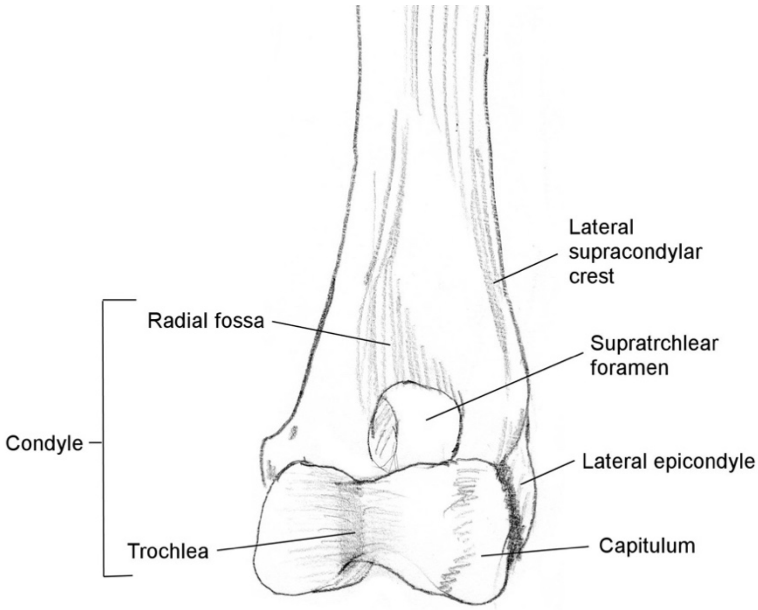

Figure 1. Left humerus, caudal aspect

The lateral and medial epicondyles are side prominences of the distal humerus (Fig. 2). The lateral epicondyle is a place of attachment of the digital extensor muscles and lateral ligaments of the joint. Close to the lateral epicondyle there is a lateral supracondylar crest, which is the origin of the radial extensor carpi and the olecranon muscles. The medial epicondyle gives rise to the digital flexor muscles and medial ligaments of the joint (Dyce et al. 2009).

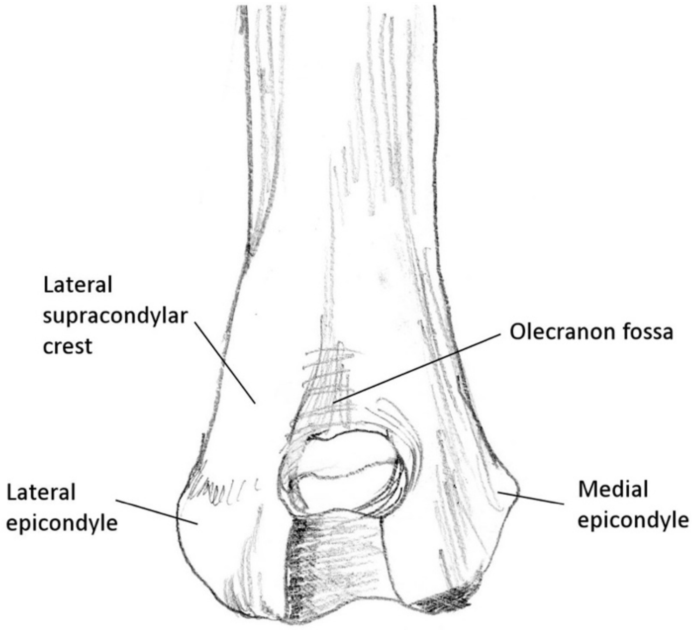

Figure 2. Left humerus, cranial aspect.

The olecranon is the most prominent part of the flexed elbow and is a part of the ulna that articulates with the humerus through the trochlear notch (Fig. 3). The trochlear notch ends proximally with the anconeal process that moves in and out within the olecranon fossa during elbow movement. Distally the trochlear notch ends with the medial and lateral coronoid processes that articulate with the humeral condyle and the proximal radius. The coronoid processes make the joint surface larger but do not contribute to a weight-bearing function of the elbow (Evans and de Lahunda 2012).

The proximal radius has mainly two articulate surfaces: the articular circumference, which articulates caudally with the ulna's radial notch, and the articular fovea, which articulates with the humeral capitulum. As described above, the radial head also takes part in articulation with the lateral part of the humeral trochlea.

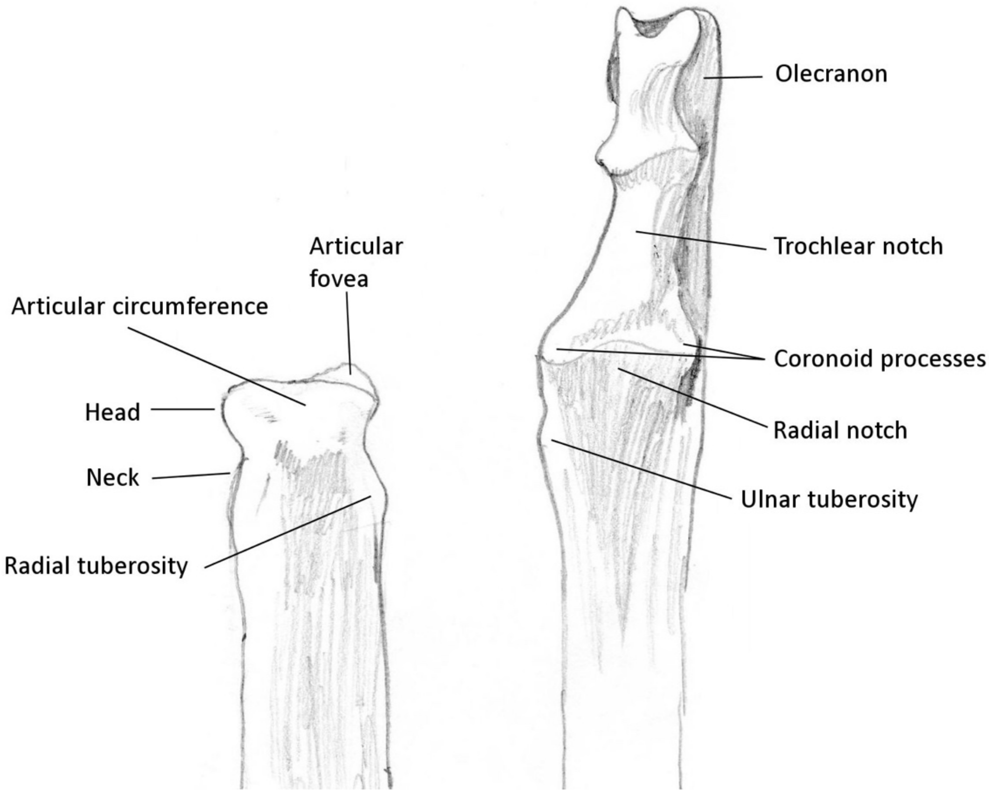

Figure 3. Left radius, caudal seurface, and left ulna, cranial surface

The cranial body weight is transmitted from the humerus to the radius through the elbow joint surfaces. The radius is a primary weight-bearing bone of the front leg in a dog, while the ulna serves mainly as an attachment place for muscles. The fovea capitis of the radius, the capitulum of the humerus and partly the trochlea are the main articulate surfaces to take part in weight transmission (Evans and de Lahunda 2012).

There are two main forms of osteogenesis, intramembranous and endochondral ossification. Intramembranous ossification is the direct transformation of mesenchymal tissue into bones, for example, as in development of patella or head bones (Gilbert et al. 2010). In endochondral ossification the cartilage plays an intermediate role before it is replaced by bone. Differentiating mesenchymal cells condense into nodules that become chondrocytes and proliferate forming the cartilage model of the future bone. Chondrocytes increase in size and undergo apoptosis calcifying their extracellular matrix. Hypertrophic chondrocytes release angiogenesis factors so that blood vessels start growing into the degenerating cartilage tissue. Osteoblasts come with the blood supply and deposit bone tissue. The second centers of the ossification form in the opposite ends of the bone with their own blood supply (Horton 1990). The ossification is regulated by transcription factors, hormones, nutrition, and mechanical forces (Le Veau and Bernhardt 1984).

Endochondral ossification of the humeral condyle in a dog starts at the age of 6-22 days after birth (Dyce et al. 2002). The humeral condyle has two centers of ossification: lateral and medial, the former one develops into the capitulum and the latter into the trochlea. These ossification centers unite at the age of 8-12 weeks (Hare 1961) and close at the age of 5-8 months (Smith and Allcock 1960). Alternatively, ossification centers might close as early as 4 months of age (Carrera et al. 2008).

2. ETIOPATHOGENESIS OF HUMERAL INTRACONDYLAR FRACTURE

The spaniels have been noted to be predisposed to humeral condylar fracture more than other breeds. In this breed the fractures could occur also during normal activity, like running, climbing stairs, jumping from low surfaces (Marcellin-Little et al. 1994). In two studies the limbs with the unaffected humeral condyles opposite to the limb with the humeral condyle fracture, were examined with radiography and tomography and the intracondylar fissure was found (Marcellin-Little et al. 1994, Martin et al. 2010). It was proposed that the fissure is the result of incomplete ossification of the humeral condyle hereinafter IOHC. IOHC in its turn is a predisposing factor to the humeral condyle fracture (Marcellin-Little et al. 1994). Later on, other medium-to-large breeds were found to be affected: Labrador retriever (Robin and Marcellin-Little 2001, Meyer-Lindenberg et al. 2002), German Wachtel (Meyer-Lindenberg et al. 2002), Doberman pinscher (Piola et al. 2012), German Shepherd (Meyer-Lindenberg et al. 2002, Martin et al 2010), Rottweiler (Rovesti et al. 1998). Nevertheless, in most of the studies spaniels have been overrepresented.

There are two hypotheses of the origin of the humeral intracondylar fissure. One states that the fissure is the result of incomplete ossification of the humeral condyle as initially stated by Marcellin-Little et al in 1994. According to the other hypothesis fissure is the stress fracture induced in the abnormally developed bone. The latter was first suggested by Butterworth and Innes in 2001. Because of unclear etiology of the disease, it was suggested that the more appropriate term for describing the pathology is the humeral intracondylar fissure (Farrell et al. 2011).

2.1 Incomplete ossification hypothesis

If the ossification centers in two parts of the humeral condyle fail to fuse, one might see on the X-ray picture a radiolucent line separating the two parts. The line runs from articular surface of the elbow joint to the supratrochlear foramen. The line might be just partial as well (Marcellin-Little et al. 1994, Witte et al. 2010). Histologically this unossified area consists of dense cancellous bone and fibrous connective tissue. The biopsy samples taken during the surgery of the humeral fractures as a result of IOHC showed the osteoclastic activity and increased number of plasma cells (Marcellin-Little et al. 1994). This suggests chronic inflammation process but does not provide proof for IOHC hypothesis because of the absence of cartilage tissue in the area of the fissure. Although one study showed some irregular cartilage proliferation in biopsies taken from the German Shorthaired Pointer dog's elbows (von Pfeil et al. 2010). However, this breed is not typical for the disease, the more biopsy cases from typical breeds are required to confirm IOHC theory.

In 2008, Carrera et al. argued that humeroulnar incongruence can be the reason for the incomplete ossification followed by the same assumption proposed by Butterworth and Innes in 2001. Carrera et al. (2008) conducted a study, where computed tomographic features of IOHC were described, and found out that there was humeroulnar incongruence in 75% of affected elbows as well as medial coronoid disease in 26%. Authors proposed that incomplete ossification of the humeral condyle might be the result of elbow dysplasia. If biopsy findings by von Pfeil et al. (2010) and humeroulnar incongruence findings by Carrera et al. (2008) are correct, then IOHC pathogenesis is similar to that of ununited anconeal process (UAP) in a dog (Farrell et al. 2011), where the anconeus is failed to unite with the ulna because of constant motion between them (Sjostrom et al 1995). However, in many other cases no humeroulnar incongruence was documented (Farrell et al. 2011, Piola 2012). The study that included 50 English cocker spaniels with HIF revealed that incongruency in normal elbows was not different from affected elbows (Moores et al 2012).

Phenotypic pedigree analysis of cocker spaniels suggested that IOHC may be inherited in a recessive mode and thus has a genetic basis (Marcellin-Little et al. 1994). Endochondral ossification is regulated by numerous transcription factors. One of which – histone deacetylase 4 (*hdac4*) – regulates the hypertrophy of chondrocytes. Interestingly, if this factor is overexpressed in limbs and ribs, the ossification can be ultimately delayed. When the gene coding the *hdac4* was knocked out from mice genome, mice were born with prematurely ossified ribs and limbs (Vega et al. 2004). Further genetic studies are needed to identify genes involved in pathogenesis of HIF.

2.2 Fatigue induced fracture hypothesis

Butterworth and Innes proposed that the fissure might be the result of the stress fracture. In this scenario the fissure would develop after the humeral ossification is completed. This hypothesis is supported by the research conducted in 1972, where authors proved that compression and tensile forces applied on physeal plate promote rapid ossification rather than delay it (Ehrlich et al. 1972, Reich et al. 2005). So, abnormal forces applied to the humeral condyle are unlikely to stop endochondrial ossification.

Development of the fissure is a dynamic process. In the case described by Witte et al. (2010) a propagation of the intercondylar fissure from 3 mm to 10,8 mm in length was documented. With the fissure propagation the instability of the condyle grew, and the dog described in the case became lame on the affected limb. Another case presented by Farrell et al. (2011) documented a normal elbow, in which 22 months later developed the humeral intercondylar fissure. The initial absence of the fissure and its subsequent appearance was diagnosed by computed tomography. The same appearance of the fissure was diagnosed by Piola et al. (2012) with the help of magnetic resonance imaging. Piola et al. (2012) reported a dog that had no visible fissure in the elbow contralateral to the elbow with HIF. In 7 months, the fissure was documented with the help of magnetic resonance imaging. It is incorrect to call this type of fissures incomplete ossification of the humeral condyle because in both cases the humeral condyle was either entirely ossified or, as in Witte et al. (2010) case, the majority of the condyle was ossified. Farrell et al. (2011) proposed that the lesion is called humeral intracondylar fissure (hereinafter HIF) at least until the exact pathogenesis of the lesion is known. The same terminology is used throughout this work.

In the study that investigated prevalence of HIF in English cocker spaniels all identified fissures were small and incomplete. The dogs were not lame and were scanned by CT for other purposes. In contrast to IOHC in this study condyles were ossified apart from small areas where fissures were found (Moores et al. 2012).

Stress fractures are divided into fatigue and insufficiency fractures. In fatigue fractures the tissue is constantly loaded to the point, where it fails. Insufficiency fractures happen when normal forces are applied on abnormal bone. It was shown that cycling loading of

10^6 repetitions could produce a fatigue fracture (Zioupos et al. 2001), whereas the middle active dog produces $7x10^6$ steps a year (Chan et al. 2005). So, theoretically it is possible that HIF can be a fatigue fracture.

Moores et al. (2017) described a case, where HIF was found bilaterally in a 17-week-old dog. Complete and incomplete fissures were diagnosed on computed tomography. In this dog the stress fracture seems to be unlikely because of the early age, unless the bone is abnormal, and the fracture is due to insufficiency of the bone.

IOHC seems to be a static process, whereas a stress fracture is a dynamic process. The static process assumes that the risk of humeral condyle fracture development does not depend on the size of the fissure (complete or inco1mplete). In the study of Marcellin-Little et al. (1994) incomplete fissures led to humeral condyle fractures more often than complete fissures. This fact states that the size of the fissure cannot predict the fracture risk. Although cases reported by Witte et al. (2010), Farrell at el. (2011), Piola at el. (2012) show that there was a dynamic process because the fissure either became complete or appeared de novo. As there is no universal opinion on HIF being either incomplete ossification or the stress fracture, two conditions might exist simultaneously and there are two different pathogeneses of the humeral intracondylar fissure. Although both theories can be true, the underlying cause of the condylar failure is yet to be discovered.

3. DIAGNOSIS OF HUMERAL INTRACONDYLAR FISSURE

3.1 Clinical signs

Humeral intracondylar fissure is a rare finding in a dog. Moores et al. (2012) studied the prevalence of HIF in English springer spaniel population and found out that HIF was present in 14% of elbows, while medial coronoid process disease affected 44% of elbows. Rareness of the disease might also be due to its novelty and the unawareness of many veterinarians of this condition. Diagnosis also may be challenging as the more sensitive imaging modalities are usually needed. Now, as the awareness about the disease is growing, the more cases might be diagnosed in the future.

In 1994, Marcellin-Little et al. published interesting results of the study where the evaluation of 157 dogs with the humeral condyle fracture was performed. Spaniel breed was overrepresented. Also, spaniels were more likely to have the bilateral humeral condyle fracture. 86% of those spaniels who did not have the bilateral fracture had a translucent line in the contralateral condyle (Marcellin-Little et al. 1994). In another study 6 out of 14 spaniels with humeral condyle fracture had HIF contralaterally (Martin et al. 2010).

Dogs with HIF are usually presented either with lameness or with the humeral condyle fracture secondary to HIF (Table 1). Also, HIF may be an incidental finding causing no lameness (Moores 2006).

Typical patient with HIF is a spaniel with the chronic forelimb lameness unresponsive to nonsteroidal anti-inflammatory drugs (Rovesti et al. 1998, Robin and Marcellin-Little 2001, Moores 2006). Lameness is more evident after rest and exacerbates after exercise (Robin and Marcellin-Little 2001, von Pfeil et al. 2010). It ranges from mild to non-weight bearing and can be intermittent (Robin and Marcellin-Little 2001). By the time of presentation, the clinical signs usually have lasted around 2-8 weeks (Robin and Marcellin-Little 2001, von Pfeil et al. 2010). Lameness can be bilateral, because HIF is likely to exist in both forelimbs (Marcellin-Little et al. 1994).

According to reports the median age on admission is 3.8 years, ranging from several months to 7 years (Butterworth and Innes 2001, Meyer-Lindenberg et al. 2002., Carrera et al. 2008, Hattersley et al. 2011). On physical examination pain is perceived by the dog during extension and flexion of the elbow, pronation, and supination of the antebrachium. Most often pain is noted in response to direct pressure on the lateral epicondyle (Rovesti et al. 1998, Fitzpatrick et al. 2009).

Often no previous history of trauma precedes lameness in patients with HIF. The first clinical sign, however, may be non-weight bearing lameness, which will be diagnosed as a humeral condyle fracture. Fractures due to HIF are low energy fractures. In anamnesis there is often no justifiable cause for this type of fractures. It might be simple walking, climbing the stairs, running, jumping from low surfaces or other normal activity (Marcellin-Little et al. 1994).

HIF should be suspected when the dog is of the spaniel breed and clinical findings suggest lameness and pain in the lateral epicondyle.

Table 1. Clinical presentations of patients with humeral intracondylar fracture

Degree of lameness	*Findings on imaging*	*Preceding events*
No lameness	Incomplete, small fissures	Incidental finding
Subtle lameness	Incomplete, small fissures	Aggravated by exercise
Obvious lameness, mono- or bilateral	Large incomplete and complete fissures	Aggravated by exercise
Complete fracture	Monocondular, complex condylar fractures	No trauma or minor trauma

3.2 Radiography

HIF may be confirmed by radiography, if the fissure is directly perpendicular to X-ray beams (Fig. 4). Otherwise, the fissure will not be seen (Marcell-Little et al. 1994). Martin et al. (2010) examined 14 elbows that were contralateral to the elbows with humeral condylar fracture and found out that sensitivity and specificity of radiography was 83% and 100% respectively. For radiography, the dog is positioned in ventral recumbency, forelimb is stretched, and multiple cranio-caudal radiographs are taken (Marcell-Little et al. 1994). In my opinion, one can also try to make cranio-caudal radiographs with brachial supination, as the olecranon will be less in a way of the fissure. Also, additional flexed and extended mediolateral projections may be taken to better evaluate the elbow (Fitzpatrick et al. 2009). Marcellin-Little et al. (1994) advised to direct the radiographic beam 15° cranio-medially to 15° caudo-laterally. If the fissure is not seen on radiograph, HIF cannot be ruled out (Fitzpatrick et al. 2009). Some authors also note that humeroulnar joint space is narrower in elbows with HIF (Rovesti et al. 1998).

Figure 4. Spaniel breed dog, right humeral condyle. University Veterinary Hospital, University of Helsinki, 2009.

New bone formation is frequently seen in association with HIF. The degree of the degenerative joint disease ranges from mild to severe (Meyer-Lindenber et al. 2002, Carrera et al. 2008). According to Carrera et al. (2008) mild to severe osteoarthritis was observed in 79% (30 elbows). Usually new bone formation is localized on the lateral epicondylar crest. Marcellin-Little et al. (1994) argued that osteophytes are usually seen in the elbows with complete HIF. The instability of the condyle with complete fissure might be greater and osteophytes in these cases are more probable (Marcellin-Little et al. 1994). Findings by Carrera et al. (2008) contradict with this statement showing that there is no connection between the new bone formation and completeness of fissures. In most of the affected elbows (24 elbows 80%) with complete and incomplete HIF there were osteophytes on the lateral epicondylar crest (Meyer-Lindenber et al. 2002, Carrera et al. 2008). In more severe cases of osteoarthritis, the medial epicondyle and supracondylar fossa are also affected (Carrera et al. 2008). When suspecting HIF, it is recommended to always examine and evaluate the contralateral limb because the condition is often bilateral (Marcellin-Little et al. 1994, Carrera et al. 2008, Martin et al. 2010, Farrell et al. 2011).

3.3 Computed tomography

Computed tomography is considered to be a gold standard for diagnosis of HIF (Fig. 5). It is much more sensitive than radiography for diagnosing HIF as there is no superimposition of other bone structures on the fissure (Rovesti et al. 1998, Carrera et al. 2008, Fitzpatrick et al. 2009, Martin et al. 2010). In CT images, the fissure itself is hypoattenuating. Next to it there is an area of sclerosis or increased density of bone (Robin and Marcellin-Little 2001, Meyer-Lindenberg et al. 2002, Carrera et al. 2008). For computed tomography, the dog is positioned in sternal recumbency and the forelimbs extended forward and parallel. The fissure starts at the level of the articular surface of the joint and extends to or toward the supratrochlear foramen (Carrera et al. 2008).

Carrera et al. (2008) defined the age of the dog for clinical screening of HIF: the dog must be older than 6 months. In younger dogs it is possible that two centers of ossification in the humeral condyle are not yet fused.

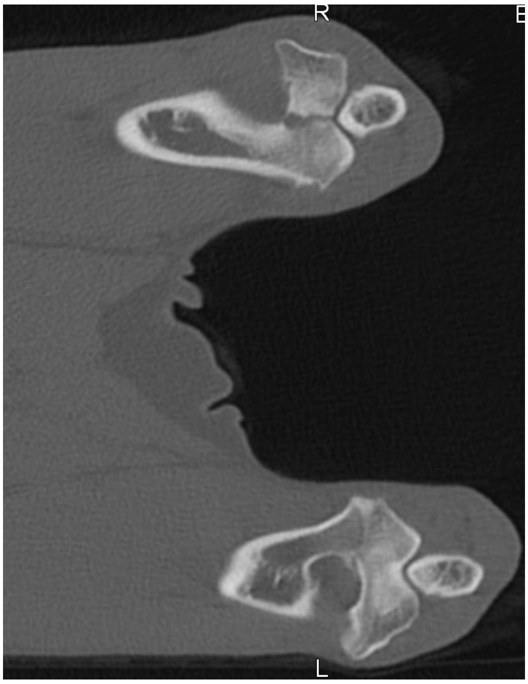

Figure 5. Computed tomography image of both canine elbow joints. Note a fissure in the right condyle. University Veterinary Hospital, University of Helsinki, 2009.

3.4 Arthroscopy

Arthroscopically HIF is well visible. This type of diagnostics is especially valuable, if other elbow pathologies are suspected, e.g., osteochondrosis dissecans and fragmented coronoid process. This modality allows simultaneous treatment of several pathologies (Meyer-Lindenberg et al. 2002). For the arthroscopical procedure, the patient is positioned in dorsal recumbency and forelimb is accessed medially. All major structures should be evaluated including the anconeal process, coronoid process, and transcondylar region (Fitzpatrick et al. 2009). In my opinion incomplete fissures that do not extend to the joint might not be visible in arthroscopy. If the lameness is intermittent and suggests incomplete fissure, this might not be the modality of choice.

3.5 Magnetic resonance imaging

Magnetic resonance imaging (MRI) has the same sensitivity and specificity in diagnosis of HIF as computed tomography (Piola et al. 2012). In addition, it has also a predictive value. In the study Piola et al. (2012) reported MRI features of HIF the authors noted edema-like lesions around the fissure area. Also, authors described a case, where the dog with unilateral HIF was 7 months later diagnosed with bilateral HIF. Both times diagnosis was made using MRI. The humeral condyle of the elbow contralateral to the elbow diagnosed with HIF appeared heterogenous on MRI. Authors concluded, if contralateral humeral condyle is heterogenous on MRI, the possibility of fissure appearing later in life should be considered.

4. TREATMENT OF HUMERAL INTRACONDYLAR FISSURE

4.1 Conservative treatment

Conservative treatment of HIF is associated with the high rate of humeral condyle fractures and unresolved lameness (Mitrovic et al. 2017). Although in case with mild clinical signs a successful conservative treatment of the disease was reported (Favril et. al. 2014, Mitrovic et al. 2017). In one report exercise restriction and dietary supplement that contained glucosaminoglucans, methylsulfonylmethane and silicone was enough for a patient to show no lameness on a follow up in 5 months (Favril et al. 2014). In another report exercise restriction and rest did not end up in good outcome in the dog with bilateral HIF as it became lame on the forelimb one year later (Mitrovic et al. 2017). CT images showed a slight propagation of fissures in both elbows. The dog was treated by drilling tunnels into the condyle for osteogenesis to occur and laser therapy. In a follow up in 1 year the dog was sound and showed no pain on palpation of the elbows (Mitrovic et al. 2017). Unfortunately, no CT images were made during the follow-ups to confirm the presence or absence of fissures. In the case describe by Favril et al. (2014) the dog was 8 months old on admission. In the younger dog the healing of the condyle is more probable because of the better bone remodeling capacities in younger animals. But no long-term outcomes were available for neither case described above. Overall, it is not recommended to treat a dog with confirmed HIF and lameness conservatively (Charles et al. 2009, Fitzpatrick et al. 2009) because it is associated with unresolved lameness and high rate of humeral condyle fracture (Marcellin-Little 1999, Meyer-Lindenberg et al. 2002).

4.2 Surgical treatment

This type of treatment aims to stabilize the humeral condyle and stop micromovements between two parts of the condyle (Marcellin-Little et al. 1994, Rovesti et al. 1998). The indication for the surgical management of the humeral condyle is lameness of the dog (Marcellin-Little et al. 1994, Meyer-Lindenberg et al. 2002, Fitzpatrick et al. 2009, Hattersley et al. 2011). The incidental finding of HIF in a dog without lameness is not by itself an indication for the surgery (Martin et al. 2010). Although some authors mention that clinically silent HIF might be prophylactically operated to prevent the possible humeral condyle fracture in the future (Marcellin-Little et al. 1994, Moores and Moores, 2017). Moores and Moores (2017) reported that 18% of incidental HIF cases developed fractures within 24 months. Marcellin-Little et al. (1994) described two cases when dogs treated for HIF surgically and diagnosed with incidental HIF in the contralateral limb, were admitted with that limb condylar fracture within 6 months. On the other hand, Meyer-Lindenberg et al. (2002) reported 6 cases diagnosed with HIF where the humeral condyle fracture did not occur in 43 months. Although the cases were not of spaniel breed.

The stabilization of the humeral condyle is usually achieved by transcondylar screw placement in lateral approach (Fig. 6), which is a traditional surgical technique in treatment of HIF before the fracture (Marcellin-Little et al. 1994, Butterworth and Innes 2001).

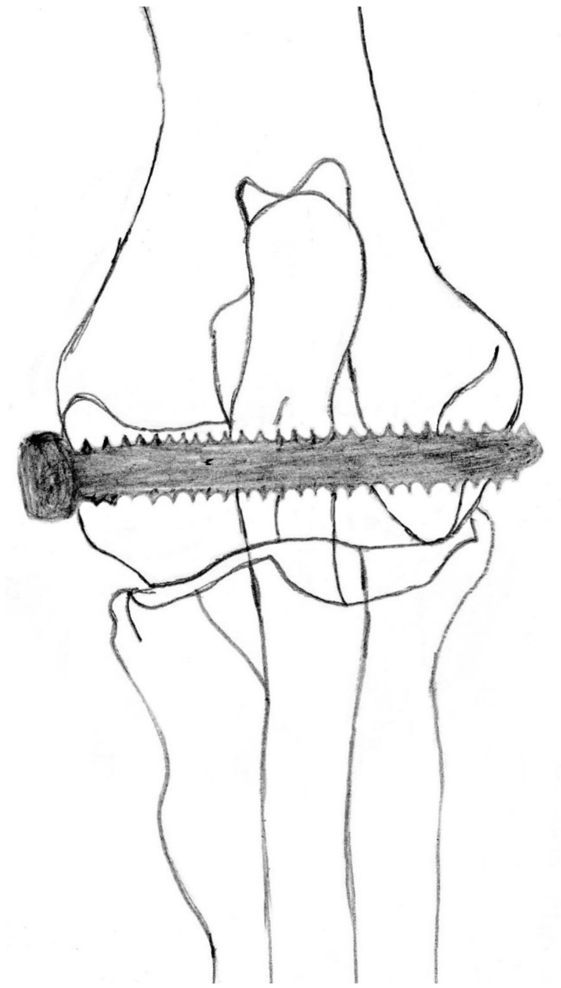

Figure 6. Transcondylar screw placement.

The correct screw placement may present a challenge for a surgeon because the screw should not end up in the joint or be too short or oblique. For postoperative assessment of accurate screw placement, it is recommended to take two radiographic views: mediolateral and craniocaudal. From craniocaudal view the screw placement line is assessed relative to a line between the epicondyles, which should be ideally parallel (Grand 2017). The screw engagement is also assessed from the same view: the exit point of the screw should be at least one thread in trans-cortex to ensure the satisfactory bone purchase (Morgan et al. 2008). In his article Grand (2017) recommended to assess the screw eccentricity relative to the trochlea's center in mediolateral view. For this assessment two circles are drawn: one is placed within the trochlear groove and a smaller one within the head of the screw. Ideally the center of the trochlear groove should coincide with the center of the head of the screw. The more accurate guidelines for correct drill placement in mediolateral and lateromedial approaches are reported by Clarke et al. (2012). It was calculated that the safe entry or exit point for drilling is 0,3 x trochlear groove diameter distal or cranial to the lateral epicondyle and 0,3 x trochlear groove diameter distal and 0,2 x trochlear groove diameter cranial to the medial epicondyle. Authors stated that medial approach has less safe corridor for the correct screw placement and intra-articulate screw placement with this approach has a bigger risk. It is advised to place a slightly longer screw because of easier location of the tip of the screw if the screw breaks and needs to be removed (Houlton 2015).

The most favorable outcome of the surgery would be the ossification of the condyle (Marcellin-Little et al. 1994, Rovesti et al. 1998). Some authors described the fusion of the condyle following the surgical treatment. Meyer-Lindenberg et al. (2002) reported 5 cases where fusion occurred, in three of which it was confirmed by computed tomography. Fitzpatrick et al. (2009) documented that fusion was achieved in 7 out 8 elbows. Unfortunately, the postoperative CT-scan does not often support that outcome and quite often the fissure is still seen months after surgery (Rovesti et al. 1998, Robin 2001). The chronic inflammation and the presence of sclerotic bone in the fissure area prevent the two parts of the condyle to fuse (Marcellin-Little et al. 1994, Hattersley et al. 2011). If HIF persists despite the screw placement, the cyclic forces acting on the implant that is not reinforced by healed bone may cause an implant failure and lead to humeral condyle fracture (Charles et al. 2009).

There are two main problems that face the surgeon, who is about to treat HIF. Firstly, it is the chronic inflammation in the sclerotic bone, which prevents humeral condyle fusion and can easily lead to implant failure (Butterworth and Innes 2001, Fitzpatrick et al. 2009, Charles et al. 2009, Hattersley et al. 2011). The second challenge is the limited place for surgical maneuvers in the isthmus of the condyle because it is very narrow. This may easily lead to intra-articular screw placement (Barnes et al. 2014, Moores et al. 2014, Grand 2017).

To overcome the challenges in treatment of HIF (Table 2), surgeons use different type of screws (Butterworth and Innes 1999, Charles et al. 2009, Fitzpatrick et al. 2009, Hattersley et al. 2011, Coggeshall et al. 2014, Moores et al. 2014), aiming devices for correct screw placement (Grand 2017, Easter et al. 2020) and fluoroscopy guidance (Moores et al. 2014, Grand 2017, McCarthy et al. 2019).

Table 2. Challenges and their solutions in HIF treatment.

Challenges in HIF treatment	Solution
Sclerotic bone leading to implant failure	Diverse types of screws: largest possible screw (4,5 mm), Fitz Fenestrated Tubular Transcondylar screw, screw placed in a lag fashion
	Screw placed in medial approach
	Drilling bone tunnels for vascularization in combination with a screw
	Bone autograph in combination with a screw
Risk of intra-articulate screw placement.	Fluoroscopic guidance
	Aiming device
	3D printed patient specific drill guides

Aiming devices guide the drill through the condyle, so the drill will not end up in a joint (Grand 2017, Easter et al. 2020). Intraopertative fluoroscopy allows to assess the correct positioning for the guide wire before drilling a corridor for the transcondylar screw (Moores et al. 2014, Grand 2017, McCarthy et al. 2019). Nowadays also many prefer medial approach to lateral, in other words, the screw is inserted in the area of medial epicondyle and comes out laterally (Moores et al. 2014, Grand 2017, Chase et al. 2019, Easter et al. 2020).

4.2.1 Placement of the largest possible screw

In most reports the diameter of the largest possible screw for an adult spaniel dog is 4,5 mm (Butterworth and Innes 2001). The screw is placed transcondylarly usually through lateral approach. There are no rotational forces in the condyle, so one implant placement is usually enough in this type of surgery. The largest possible screw is chosen because it is less prone to fatigue failure than the screws with smaller diameter. This is an important factor in HIF treatment as these types of fissures rarely heal. On the other hand, with the bigger screws there is less space for ossification of the condyle to occur (Charles et al. 2009). For springer spaniel the diameter of the largest possible screw will be 4.5 mm (Butterworth and Innes 2001, Hattersley et al. 2011, Moores et al. 2014), which is from 30% to 50% of the isthmus of the condyle (Moores et al. 2014)

Charles et al. (2009) studied broken screws that were retrieved from the elbows treated for HIF. They argued that even large screws are prone to failure in treatment of HIF. All screws were broken in the middle where HIF transects the screw in the elbow. Thus, condylar instability remains because of intracondylar nonunion and a risk of implant failure is significant (Charles et al. 2009).

4.2.2 Placement of the screw in lag fashion

The screw placed in lag fashion brings the two parts of the condyles together by compression and facilitates the ossification (Butterworth and Innes 2001, Meyer-Lindenberg et al. 2002, Hattersley et al. 2011). This will also secure implant integrity (Hattersley et al. 2011). Although there is a concern that compression might alter the articular surfaces of the elbow and promote arthritis by changing the forces acting in the joint. Meyer-Lindenberg et al. (2002) inserted the screws with the aid of arthroscopy and documented the adaptation of fissure that happened during screw placement.

Although they did not report any post-operative complications. In the study by Butterworth and Innes (2001) one elbow out of 11 that were treated by the screw placed in lag fashion developed osteoarthritis. Hattersley et al. (2011) reported that placing the screw in lag fashion reduces the overall postoperative complication rate.

Positional screw was not recommended in the studied articles (Butterworth and Innes 2001, Meyer-Lindenberg et al. 2002, Hattersley et al. 2011). Clearly this technique does not bring two condyle parts together and a risk of the bone non-union becomes higher.

4.2.3 Drilling bone tunnels across the condyle

The aim of drilling of bone tunnels into the condyle is to promote vascularization of the condyle for ossification to occur (Rovesti et al. 1998, Butterworth and Innes 2001, Mitrovic et al. 2017). In a case described by Rovesti et al. (1998) they drilled three bone tunnels perpendicular to the fissure in the condyle. This technique did not bring satisfactory results. A CT image taken in 14 days after surgery did not confirm any bone bridging. The dog treated this way was reported to have bilateral lameness in 7 months. In a mild lameness this technique brought satisfactory results together with the laser therapy as described above (Mitrovic et al. 2017). Although the case did not report any CT documented evidence that the fissure became less prominent due to drilled tunnels.

Butterworth and Innes (2001) reported the drilling of the canals in the condyle together with placing a lag screw. However, the study didn't specify if the drilling of the canals brought any better results.

4.2.4 Placement of the screw with bone autograph

In 1998, bone autograft in treatment of HIF was considered by Rovesti et al. (1998). It was noted however that the autograft may transfer into the joint and authors decided not to place it. Later Fitzpatrick et al. (2009) successfully treated 8 elbows with bone autograft and an implant (Fig. 7). One elbow was treated by autograft only. Fissure bridging of ≥ 50% in 7 of 8 elbows was documented by computed tomography. Cancellous graft or corticocancellous dowel was placed transcondylarly in medial approach. A tunnel that was drilled for a graft placement was about 75% of the condylar width. In the most distal part of the condyle a special titanium screw was placed for additional support. This type of technique uses special application systems for a screw and for a graft. The cancellous bone graft was collected from the ipsilateral humerus, whereas the corticocancellous graft was taken from proximal aspect of the tibia or distal femur. One dog that was treated with cancellous graft and a screw showed no bone union on follow up. Authors assumed that during the surgery the cancellous graft might have been damaged because of excessive packing. They argued that corticocancellous dowel is preferable because it allows to save the architecture of the graft and avoid cellular damage of a graft (Fitzpatrick et al. 2009).

For a donor site Fitzpatrick et al. (2009) recommended the femoral condyle because the dowel can be taken entirely in appropriate length and with appropriate contour of the cortical surface. Authors reported the complication on the donor site in one dog, which was the surgical site infection (Fitzpatrick et al. 2009).

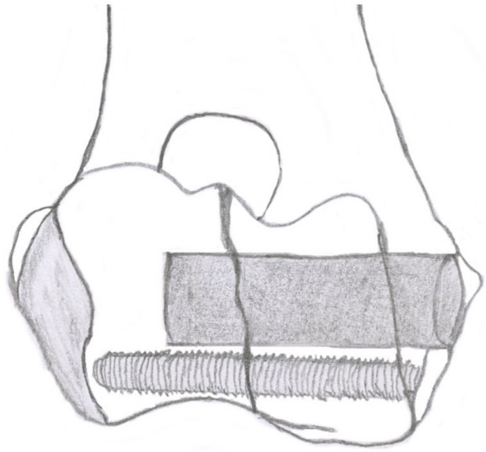

Figure 7. Surgical treatment of humeral intracondylar fissure. The bone autograft is placed above the screw.

4.2.5 Placement of the Fitz Fenestrated Tubular Transcondylar (F^2T^2) screw

The F^2T^2 screw is a 6 mm cannulated titanium screw, inside of which there is a space for bone autograft. The slots made into the screw allow the bone in-growth (Fitzpatrick and Solano, 2012) (Fig. 8). F^2T^2 was proven to have superior mechanical properties to 4.5 mm cortical screw that is usually used in surgical treatment of HIF, although there was no difference in mechanical properties when screws were cyclically loaded on cadaveric material (Coggeshall et al. 2013). Thus, the screw is designed to better counteract cycling force acting on the humeral condyle and at the same time allow rapid ossification. Fitzpatrick and Solano (2012) reported the successful treatment of HIF in 6 dogs with the screw. The bone bridging was documented by CT in all cases 12 weeks post-operatively. The follow up was available only for 14 months, so there is no evidence, if F^2T^2 screws did not fail after the follow up period. The hollow screw may not give as much resistance to fatigue and cycling forces as solid core screw. The longer follow up is needed for assessment of this specific screw.

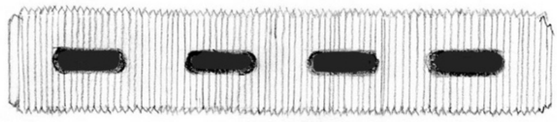

Figure 8. Fitz Fenestrated Tubular Transcondylar screw that has slots for bone in-growths.

4.2.6 Placement of the partially threaded screw

Transcondylar shaft screw is threaded partially, approximately to one third of its length (Fig. 9). It is placed in a lag fashion to reach the compression between two parts of the humeral condyle. The shaft of the screw has the same diameter as the thread screw (Moores et al. 2014). The fully threaded transcondylar screw typically used in treatment of HIF fails at the site of the fissure in the humeral condyle (Charles et al. 2009). Due to a bigger diameter the shaft screw has fatigue advantage compared to fully threaded screws. It should be placed in a way so that the shaft bridges the fissure because this is the implant's weakest point and a place of breakage (Moores et al. 2014).

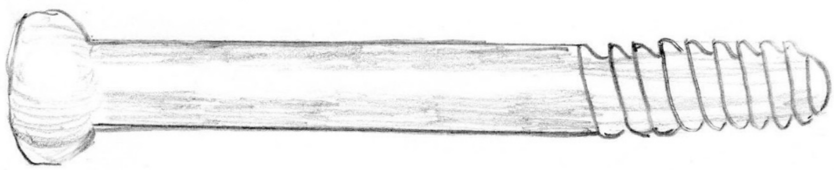

Figure 9. Partially threaded shaft screw that is supposed to have better fatigue resistance than a threaded screw.

Area moment of inertia measures the resistance of the screw to bending. It is calculated using the radius of the core diameter of the screw: $\pi\tau^4/4$ (Muir et al. 1995). The 4.5 mm transcondylar cortical screw core diameter is 3.0 mm, so the area moment of inertia is 64 mm^4, which is three times less than that of shaft screw's (201 mm^4). Moores et al. (2014) reported that 3 of 7 dogs did not have any bone bridging in the humeral condyle after shaft screw surgery. In one case the screw backed off, which was never reported with fully threaded screws. Partially threaded screw has lower purchase surface or friction with the bone than the fully threaded screws. This may predispose the screw to loosening.

4.2.7 Percutaneous screw fixation

This approach aims to help a surgeon place and orientate the transcondylar screw accurately in the humeral condyle. The technique is also claimed to be minimally invasive. As mentioned above the isthmus of the humeral condyle is narrow and intra-articular screw placement is not rare. This approach uses a special aiming device for a correct placement and orientation of the screw. It is a "C-shaped" device that has a

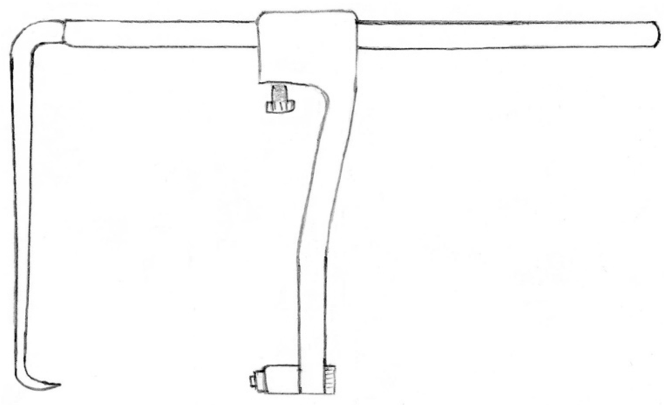

Figure 10. Aiming device for correct transcondylar screw placement. The trocar end fixates the device on the elbow and the drill sleeve guides the drilling.

trocar end on one side and a drill sleeve on the other (Fig 10). The device guides the screw by locating entry and exit point for the screw. It is important to fix the device correctly on an elbow, so the initial placement of the screw is correct (Grand 2017). As described above it is recommended to measure the diameter of the trochlear groove using a mediolateral radiograph of the elbow and then calculate the safe entry or exit point for drilling (Clarke et al. 2012). Grand (2017) reported a successful treatment of 4 elbows with this aiming device. There were no short-term post-operative complications in these cases. One of the advantages of the technique is that it may reduce the surgical site infection rate, which is high in surgical treatment of HIF (Grand 2017). Disadvantages of this surgical technique are the availability of the aiming devices in veterinary practices and the possible slipping of the devices during the surgery (Easter et al. 2020).

4.2.8 Placement of the screw in medial approach and use of a special aiming device

Using medial approach in surgical treatment of HIF is reported to have much less complications compared to a lateral approach (Fitzpatrick and Solano 2012, Moores et al. 2014). Chase et al. (2019) reported that many British surgeons use this approach successfully nowadays.

However, this approach is more challenging than the lateral one because of the higher risk of intra-articulate screw placement. There are methods that are designed to facilitate correct placement of the screw in medial fashion. Some of them, fluoroscopic guidance (Moores et al. 2014, Grand 2017, McCarthy et al. 2019) and aiming devices (Grand 2017) were mentioned above. Recently Easter et al. (2020) came up with three-dimensional printed patient-specific drill guides. Intraoperative fluoroscopy has the disadvantage of the medical staff exposure to ionizing radiation. In addition, it is not easily available in veterinary practices. Aiming devices that are commercially available can be helpful, although they may accidentally slip. Three-dimensional printed drill guides are made according to patient's specific anatomy with the help of computed tomography and special software (Fig. 11). The authors reported the maximum of 5 degrees of screw angulation and no intra-articulate placement. In this technique the patient's humeral condyle is first reconstructed with the help of computed tomography. Then in special software a 5-mm cylinder is placed within the reconstructed condyle in such a way that entry point is just cranial to medial epicondyle and exit point is distal to lateral epicondyle. The guide is designed around the cylinder. The guide itself represents two key features: a sleeve for a pilot hole that guides the drill in a right direction and a base that covers cranial, caudal, and proximal aspects of the medial epicondyle. The base repeats the contours of the bone in inverted manner, so, when attaching to the bone it will become very stable. In their study Easter et al. (2020) argue that this guide allows to use the 5-mm screw instead of usual 4.5-mm because of the accuracy of placement, thus, making fatigue failure of the screw less probable. This is just a hypothesis because no studies have been done on this so far. The disadvantages of this method are the unavailability of the special software and three-dimensional printing in veterinary practices. Also, authors describe that for the accurate placement of the base of the guide the flexor carpi radialis muscle should be elevated. After the procedure, the muscle is sutured back. This might prolong the recovery period. Although no higher morbidity was reported in this study.

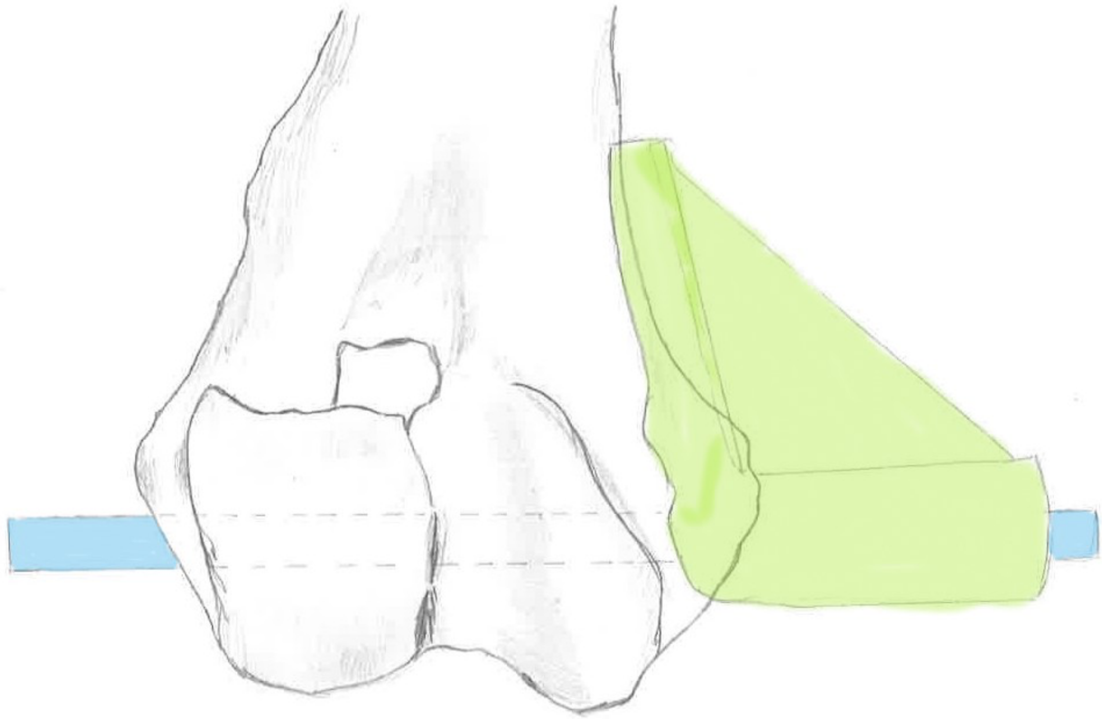

Figure 11. Reconstruction of the right humeral condyle. A 5 mm cylinder is placed within the condyle (in light blue). 3D printed drill guide is designed around the cylinder (in light green).

4.2.9 Elbow reconstruction after humeral condylar fracture

As mentioned above the first sign of the HIF can be humeral condylar fracture, which will typically result from a low-energy activity. In this case the surgical technique is more complicated because fixation happens at least in two planes: transcondylarly with a screw and epicondylarly with plates and wires to stop rotation against the screw (Butterworth and Innes 2001). HIF most often leads to the fracture of the lateral condyle (Marcellin-Little et al. 1994, Carrera et al. 2008, Houlton 2015). This type of fracture requires stabilization of the condyle with a screw and anti-rotational K-wire through the fracture or a small plate (Houlton 2015). Treating humeral condyle fractures, it is important to remember that if there is no evidence of trauma in anamnesis and the breed is spaniel, it is good to take images of both elbows, as the condition is often bilateral (Marcellin-Little et al. 1994).

Medial, T- and Y- shaped fractures are less common (Farell et al. 2011). Moores et al. (2014) reported that Y-fractures appeared to be associated with more major trauma than lateral condyle fractures in dogs with HIF. In the study by Carrera et al. (2008) there were no major trauma associated with Y-fractures. In their study Y-fractures and lateral condylar fractures occurred after normal or low energy activity.

With T- and Y-fractures separation of the two parts of the humeral condyle from the humeral shaft happens. They require robust fixation of the condyle first attaching the medial portion to the diaphysis of the humerus and after that – the lateral portion (Houlton 2015). T- and Y-fracture repairment can be particularly challenging and beyond the scope of this thesis.

5. POSTOPERATIVE COMPLICATIONS

Unfortunately, a postoperative complication rate of the surgical management of HIF is high (Table 3). Hattersley et al. (2011) studied 79 elbows operated at 6 UK referral centers and reported complication rate of 60%. The most reported postoperative complications are seroma, surgical site infection (Hattersley et al. 2011, McCarthy et al. 2019, Chase et al. 2019) and implant failure (Chase et al. 2019). The two latter are considered major complications.

According to the findings by Hattersley et al. (2011) the rate of surgical site infection was 30.7% higher than in other elective procedures. They identified two risk factors: the placement of positional screw instead of lag screw and increased body weight (Hattersley et al. 2011). The possible reasons behind this complication can be the placement of the screw in abnormal sclerotic bone (Hattersley et al. 2011), the constant instability in the condyle (Charles et al. 2009) and bone tissue necrosis due to hot temperatures during the sclerotic bone drilling (Tehemar 1999).

The second major complication - implant failure - occurred in 2 out of 57 dogs according to the study by Hattersley et al. (2011). The risk factor was the higher weight. The implant failure happens due to cyclic loading on the implant and can occur years after surgery. Failure occurs in the area, where the fissure transects the screw. Charles et al. (2009) who studied failure mode of 5 screws, reported that implant failure happened 11 – 36 months after surgery. The implant failure rate tends to be higher in spaniel breeds treated for humeral condyle fractures than in other breeds (Marcellin-Little et al. 1994). Also, with implant failure refracture is a risk (Moores et al. 2014).

Some authors report significantly lower complication rates. But their follow up times tend to be quite short. Butterworth and Innes (2001), who studied 11 elbows treated surgically for HIF, reported one implant failure with concurrent humeral condyle fracture in 14 months after surgery. Overall, 2 out of 11 elbows had complications that needed further surgical intervention. Most spaniels were lost to follow up in 3 months (Butterworth and Innes, 2001). Moores et al. (2014) reported lower complication rate with shaft screw placement – 23%, although healing of the fissure was inconsistent. Median follow up was 2 years. A good outcome was reported by Meyer-Lindenberg et al. (2002) in 7 elbows of 10 treated with the transcondylar screw. Although median follow-up was about 1 year.

As for other breeds, two Labradors were reported to have no lameness 7 months after screw placement surgery, although the fissure line did not heal in one of them (Robin and Marcellin-Little 2001). The Rottweiler was reported sound in several months after surgical HIF treatment (Rovesti et al. 1998). The longest follow up – around 10 years - was reported on the German Shephard that was treated bilaterally and had no range of motion in both elbows, although the quality of life was for some reason satisfactory (von Pfeil et al. 2010).

The surgical technique, concerning the use of bone autograft together with screw fixation, is reported to have lower complication rates. Fitzpatrick et al. (2009) who used bone autografts in surgical procedures, reported 8 out of 9 dogs to be free of lameness (6-45 months). Although the median follow-up was about 1 year. In 2012, Fitzpatrick and Solano reported that all 12 treated elbows were bone bridging short-term (12 months).

In 2019, Chase et al. argued that medial approach in transcondylar screw placement might have much lower postoperative complication rates. They reported high complication rate in cases, when the lateral approach was used: 18 out of 26 dogs had complications. Surgical site infection was reported in 11 dogs and implant failure in 1 dog. Clarke et al. (2012) earlier reported that only 3 out of 31 dogs treated in medial approach had complications. Median follow-up period was only 6 weeks though. The research done by McCarthy et al. (2019) showed higher complication rate with medial approach. They studied long-term outcomes in cases, when the transcondylar screw was placed in medial approach, and reported 57% complication rate in 14 elbows treated for HIF. 3 elbows suffered major complications. Every elbow was treated using fluoroscopic guidance. They described a median of 10-day period from the surgery to appearing of complications. Median follow up time was 6 years.

Table 3. Post-operative complication rate in treatment of humeral intracondylar fissure as reported in several studies

Publications	Surgery technique	Number of cases (elbows)	Complication rate (major complication rate)	Follow-up period (in weeks)
Chase et al. 2019	TCS, lateral approach	26	69% (50%)	56–436, median 159–206
McCarthy et al. 2019	TCS, medial approach	14	57% (21%)	182–443, median 297
Moores et al. 2014	Shaft TCS in lateral or medial approach	14	32% (32%)	26–227, median 126
Clarke et al. 2012	TCS, medial approach	31	10% (6%)	6–80, median 6
Hattersley et al. 2011	TCS or positional transcondylar screw	79	60% (25%)	6–192, median 7
Fitzpatrick et al. 2009	TCS with bone autograft	9	22% (11%)	24–180, median 56
Meyer-Lindenberg et al. 2002	TCS, medial or lateral approach	11	36% (0%)	24–300, median 55
Butterworth & Innes 2001	TCS, medial approach	9	22% (22%)	2–212, median 12

TCS, transcondylar cortical screw placed in lag fashion

6. PROGNOSIS

The prognosis associated with HIF depends on several factors. Firstly, the spaniel breed is predisposed to this condition. HIF is often bilateral in these dogs (Marcellin-Little et al. 1994, Moores et al. 2014). Moores et al. (2014) reported 14% of HIF in English springer spaniels. Marcellin-Little et al. (1994) reported 86% of HIF in elbows contralateral to the elbows with humeral condyle fracture in spaniels. It is recommended to scan a contralateral elbow in a spaniel with the humeral condyle fracture or HIF (Marcellin-Little et al. 1994, Martin et al. 2010). As the condition has a recessive mode of inheritance Marcellin-Little et al. (1994) advised against the breeding of spaniels with HIF. They proposed that the elbows of the dogs whose littermates were affected should be radiographed before their use in breeding.

Prognosis is also affected by the fact that HIF often coexists with other elbow abnormalities (Rovesti et al. 1998, Robin and Marcellin-Little 2001). Marcellin-Little et al. (1994) reported that 25% of elbows with HIF had fragmented coronoid process (FCP). Moores et al. (2012) reported 44% or 44 elbows had abnormalities of the medial coronoid process and 60% or 60 elbows had periarticular osteophytes. Meyer-Lindenberg et al. (2002) found 2 elbows with FCP and 2 with osteochondritis dissecans within 17 studied elbows. Carrera et al. (2008) reported that 26% or 10 elbows had medial coronoid disease coexistent with HIF and 75% or 19 elbows had humeroulnar incongruence. Also, it is worth mentioning that degenerative joint disease is associated with HIF. Marcellin-Little et al. (1994) found out that 67% of dogs with HIF had osteoarthritis changes in the affected elbows.

Short-term prognosis depends on the surgery technique. If the surgery is performed traditionally, with transcondylar cortical screw in lateral approach, the overall prognosis is guarded because of the high complication rate (Hattersley et al. 2011, Chase et al. 2019). Farrell et al. (2010) even reported the euthanasia of the dog treated for HIF in one elbow and humeral condyle fracture in another. The dog was euthanized because of multiple complications like implant failure and fracture nonunion. Lower short-term complication rate is associated with bone autograft technique and medial approach (Fitzpatrick et al. 2009, Solano and Fitzpatrick 2012, Chase et al. 2019. Although there is no data on long-term complications with these techniques. Medial approach of screw placement has brought its own difficulties. The chance of intra-articular screw placement is higher with this approach. According to Clarke et al. (2012) this was reported in up to 9% of the operated canine elbows. Moreover, recently McCarthy et al. (2019) reported that the long-term complication rate is high in medial approach.

Because of the high postoperative complication rate with this condition the communication with owner is particularly important. The surgical site infection as being the most common complication (Martin et al. 2010, Hattersley et al. 2011,) should be mentioned to the owner before planning the treatment.

With incidental HIF findings the surgery is not usually recommended because of the high postoperative complication rate (Martin et al. 2010). Meyer-Lindenberg et al. (2002) reported 6 cases diagnosed with HIF where fracture did not occur in 43 months. Although the owner should be informed about possible “minimal trauma” fracture of the elbow. 3 of 6 dogs with HIF in one elbow and humeral condyle fracture in contralateral elbow developed lameness signs in elbow with HIF on re-examination (Martin et al. 2010). Also, it is worth mentioning to the owner that HIF may lead to fracture through a short period of lameness as reported by Marcellin-Little et al. (1994) where two incomplete fissures led to the humeral condyle fractures in 6 months since diagnosis.

Authors that studied incidental HIF reported the follow-ups only up to 24 months (Moores and Moores 2017), which can mean that risk of fracture of the affected elbow can be much higher. Also, complex condylar fractures of the distal humerus can be particularly challenging to operate leading to excessive costs of treatment.

DISCUSSION

The etiopathogenesis of HIF remains debatable. If the theory of incomplete ossification of humeral condyle is correct, the treatment is to facilitate the bone ossification by bringing the condyles tightly together and transferring the bone autograft. The refracture of the condyle in this case would be less likely. If we assume that the fissure appears because of normal loading on abnormal bone, the placement of the biggest possible lag screw would be the best option. Without good implant support the refracture of the condyle would be a matter of time. More research is needed to establish the etiopathogenesis (-es) of HIF.

CT is a golden standard for diagnostics of HIF (Carrera et al. 2008). Radiography alone cannot be used to rule out HIF because the fissure can be overseen due to the overlapping olecranon. We recommend taking multiple cranio-caudal radiographs with supinated antebrachium. In this case olecranon is less likely to cast a shadow on the possible fissure.

HIF has a recessive mode of inheritance (Marcellin-Little et al., 1994). Spaniel dog breeders could play a significant role in prevention of the disease by choosing the mating dogs with healthy elbow joints. Screening of the elbow joints after assumed humeral condyle ossification has ended is the most reliable option. It can be impractical because CT is expensive and on radiography the fissure can be easily overseen. The alternative would be to advise the breeders against breeding the spaniel breed dogs, whose parents or littermates were diagnosed previously with HIF.

Despite different implants and bone autographs used to treat HIF, the postoperative complication rate of the condition remains remarkably high (Hattersley et al. 2011, McCarthy et al. 2019). Post-operative complications usually result from inability of the fissure to heal. Lag screw fixation in lateral approach alone is not enough to treat the condition. Chase et al. (2019) reported that many British surgeons use medial approach successfully nowadays. Interestingly, that there is no explanation in the articles, why medial approach brings less complications. To our understanding the medial part of the condyle is bigger than the lateral one and compression of the lateral part to the medial brings more stability to the elbow joint. Although the latest research showed that long term follow-ups were not satisfactory with this approach (McCarthy et al. 2019). Better surgery solutions are yet to be found to treat this condition.

Based on the reviewed literature we recommend using a transcondylar screw placed in lag fashion. One can use either medial or lateral approach as there is no difference in complication rate long-term. Because of a substantial risk of intra-articulate screw placement with the medial approach, assisting tool like fluoroscopy, arthroscopy or aiming device can be used (Grand 2017, McCarthy et al. 2019, Easter et al. 2020). Also, with either approach the bone autograft should be placed. Fitzpatrick et al. (2019) reported fissure bridging in postoperative CT in 7 out of 8 elbows treated with bone autograft placement. Although there were no data on long-term complication rate in these cases.

The bone autograft placement brings its own difficulties because it requires the opening of the donor site, which prolongs the time of the surgery and may result in postoperative complications at the donor site (Myeroff and Archdeacon 2011). The most common complications are hematoma, seroma and infection at the donor site (Arrington et al. 1996). Fitzpatrick et al. (2019) reported the donor site infection in one out of 8 dogs.

Because of high complication rate it is not recommended to operate the elbows affected with clinically silent HIF (Hattersley et al. 2011). In our opinion the decision to operate the elbow with incidental HIF still can be considered. Marcellin-Little et al. reported the case when two of four dogs that were treated surgically for HIF and had incidental HIF finding in the contralateral limb fractured that limb in 6 months (1994). Respectively Moores and Moores (2017) reported that 18% of incidental HIF cases progressed to fractures within 24 months. Moreover, as mentioned above, complex condylar fractures of the distal humerus can be challenging and expensive to operate. We agree with Moores and Moores (2017) on their recommendation to discuss the risks of future fractures and postoperative complications with the owner and let them decide if they want a prophylactic surgery.

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